NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 314

DRAG AND COOLING WITH VARIOUS FORMS OF COWLING FOR A "WHIRLWIND" RADIAL AIR-COOLED ENGINE—II

By FRED E. WEICK

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		{km/hr		mi./hr	M. P. H.
		{m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL REPORT NO. 314.

DRAG AND COOLING WITH VARIOUS FORMS OF COWLING FOR A "WHIRLWIND" RADIAL AIR-COOLED ENGINE-II, by Fred E. Weick.

E R R A T A

Figure 4 should read: Cowling No. 11.

Figure 7 should read: Cowling No. 2a.

Note.- Numbers painted on the cowlings and appearing in Figures 10, 11, 19, 25, and 26 have no meaning in connection with the text of the report.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. It consists of 12 members who are appointed by the President, all of whom serve as such without compensation.)

REPORT No. 314

DRAG AND COOLING WITH VARIOUS FORMS OF COWLING FOR A "WHIRLWIND" RADIAL AIR-COOLED ENGINE—II

By Fred E. Weick

SUMMARY

This report gives the results of the second portion of an investigation in the Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics, on the cowling and cooling of a "Whirlwind" J–5 radial air-cooled engine. The first portion, which is reported in N. A. C. A. Technical Report No. 313, pertains to tests with a cabin fuselage. This report covers tests with several forms of cowling, including conventional types, individual fairings behind the cylinders, individual hoods over the cylinders, and the new N. A. C. A. complete cowling, all on an open cockpit fuselage. Drag tests were also made with a conventional engine nacelle, and with a nacelle having the new complete cowling.

In the second part of the investigation the results found in the first part were substantiated. It was also found that the reduction in drag with the complete cowling over that with conventional cowling is greater with the smaller bodies than with the cabin fuselage; in fact, the gain in the case of the completely cowled nacelle is over twice that with the cabin fuselage. The individual fairings and hoods did not prove effective in reducing the drag. The results of flight tests on an AT–5A airplane (reported in the appendix to N. A. C. A. Technical Report No. 313) have been analyzed and found to agree very well with the results of the wind tunnel tests.

INTRODUCTION

This report covers the second and final portion of an investigation of the cowling and cooling of radial air-cooled engines. The first portion, which dealt with the cowling of a "Whirlwind" engine in a cabin fuselage, has been reported in N. A. C. A. Technical Report No. 313 (Reference 1).

The original program included 10 main forms of cowling for a "Whirlwind" J–5 engine, Nos. 1 to 3, on an open cockpit fuselage and Nos. 4 to 10 on a cabin fuselage. The seven forms of cowling on the cabin fuselage ranged from the one extreme of an entirely exposed engine to the other extreme of a totally inclosed engine. Only the first three degrees of cowling were to have been tested on the open cockpit fuselage, and one of these included individual fairings behind each cylinder. During the progress of the tests the following additions were made to the program:

(*a*) The complete cowling (No. 10 on the cabin fuselage) was tested on the open cockpit fuselage also and called cowling No. 11.

(*b*) Tests were made with individual hoods over the cylinders on the open cockpit fuselage.

(*c*) Two nacelles were tested for drag, one with the complete cowling and one with a conventional cowling. A drag test was also made on the uncowled engine by itself.

METHODS AND APPARATUS

The tests were made in the Twenty-Foot Propeller Research Tunnel, which is of the open-throat type with an air stream in which velocities up to 110 M. P. H. can be obtained. The tunnel with its balances and other equipment is described more completely in Reference 2.

A standard 9-cylinder Wright "Whirlwind" engine developing 200 HP. at 1,800 R. P. M. was used for the tests. The open cockpit fuselage was similar in shape to that of a Vought UO–1 except that the usual break in the bottom contour at the back of the cowling was filled

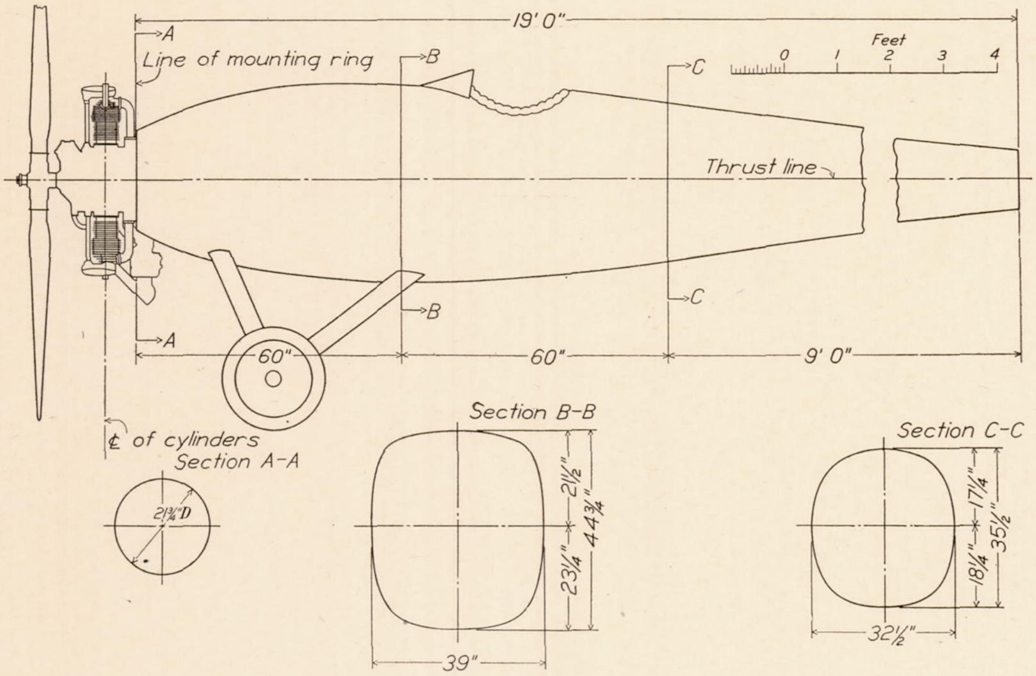

FIG. 1.—Cowling No. 1

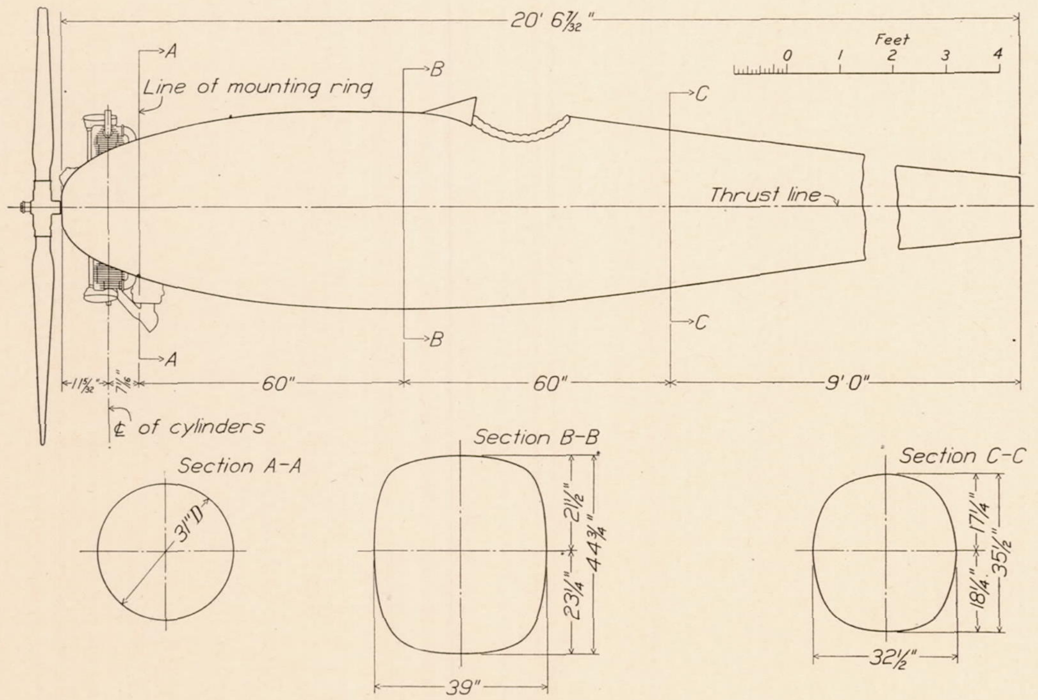

FIG. 2.—Cowling No. 2

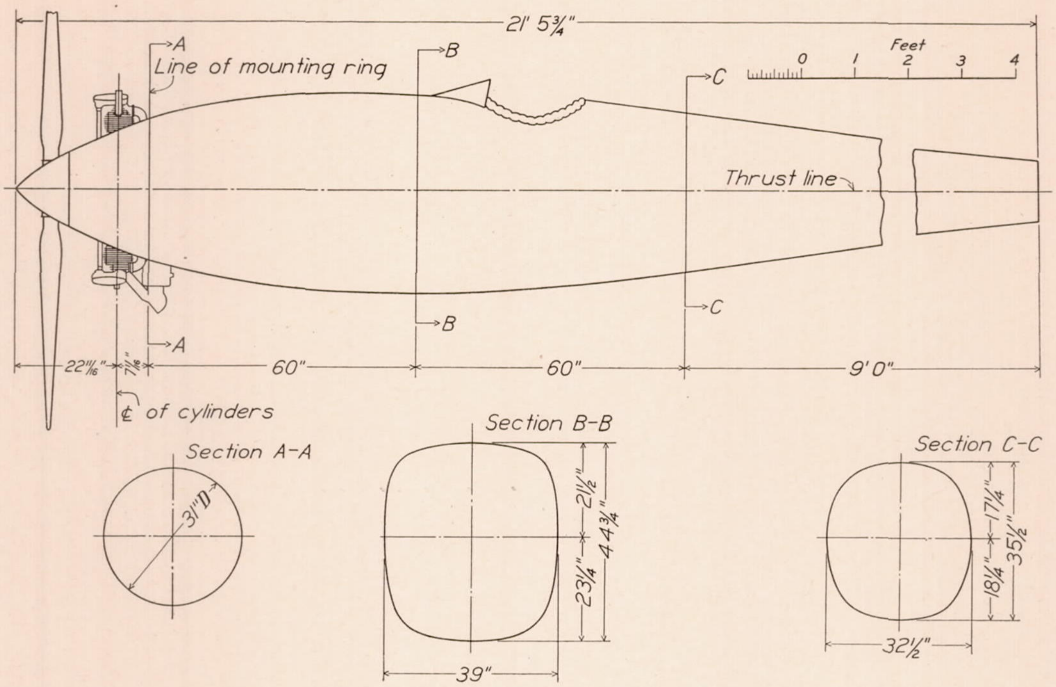

FIG. 3.—Cowling No. 3

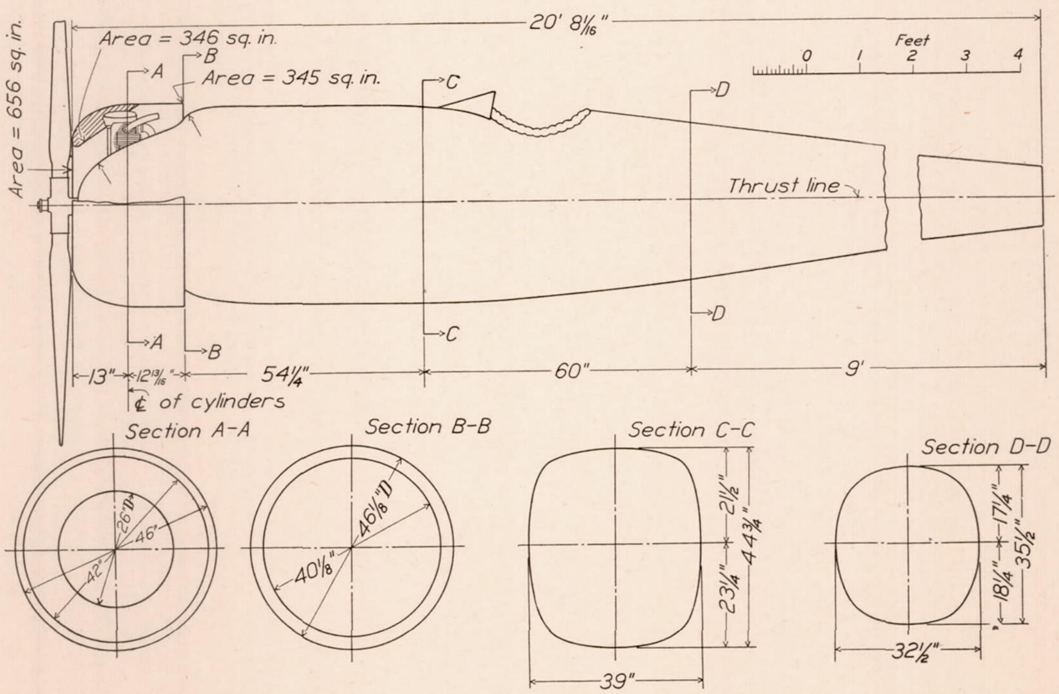

FIG. 4.—Cowling No. 4

NOTE.—Cross hatch section of cowling is not solid.

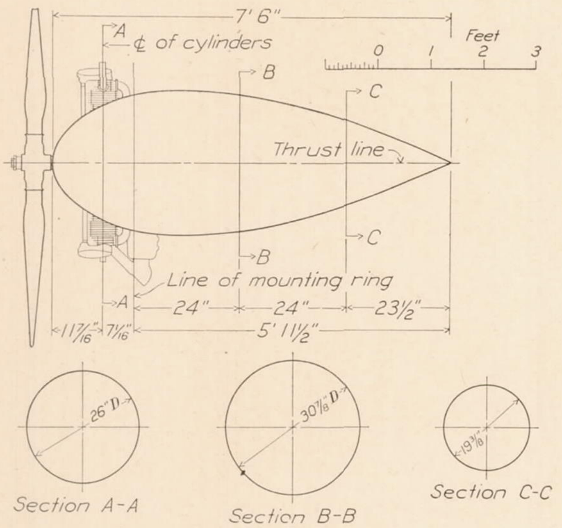

FIG. 5.—Nacelle No. 13

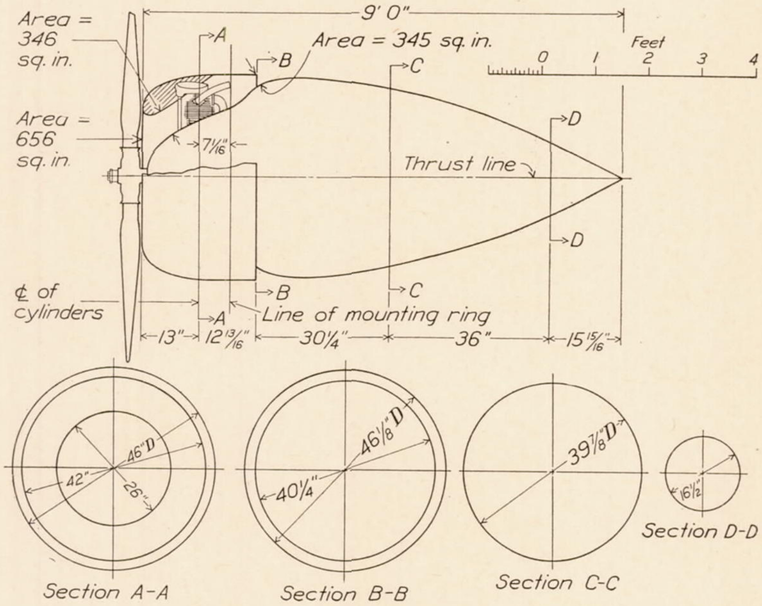

FIG. 6.—Nacelle No. 14

NOTE.—Cross hatch section of cowling is not solid

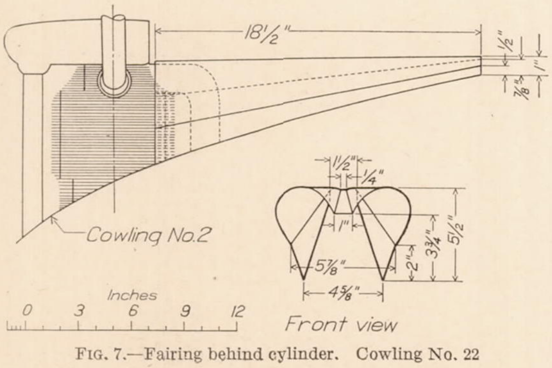

FIG. 7.—Fairing behind cylinder. Cowling No. 22

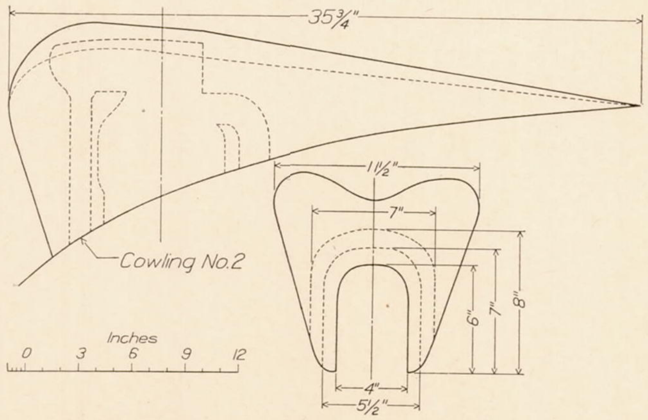

FIG. 8.—Hood over individual cylinders. Cowling No. 2c

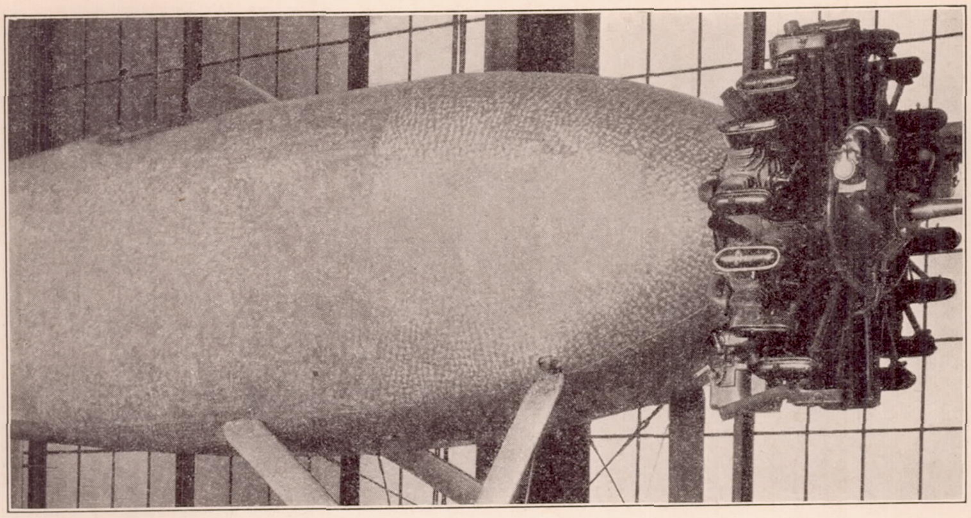

FIG. 9.—Cowling No. 1

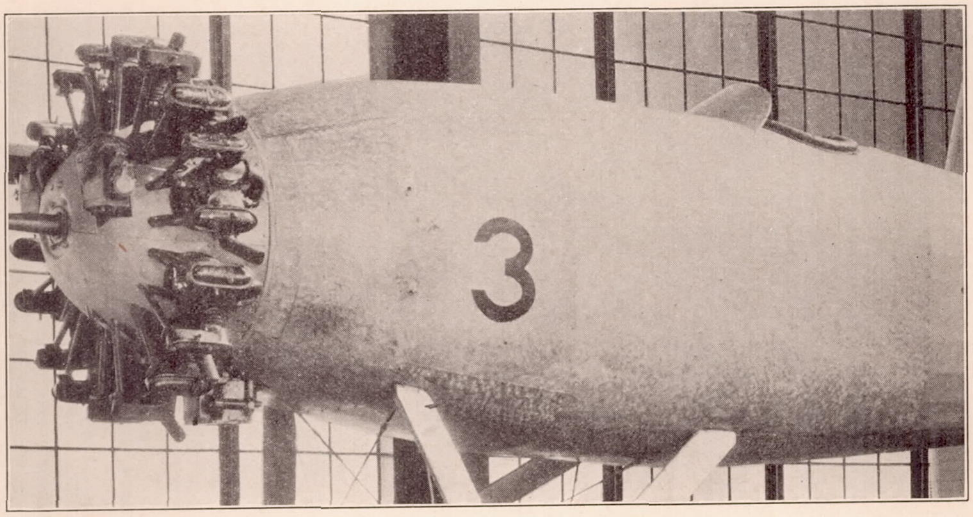

FIG. 10.—Cowling No. 2

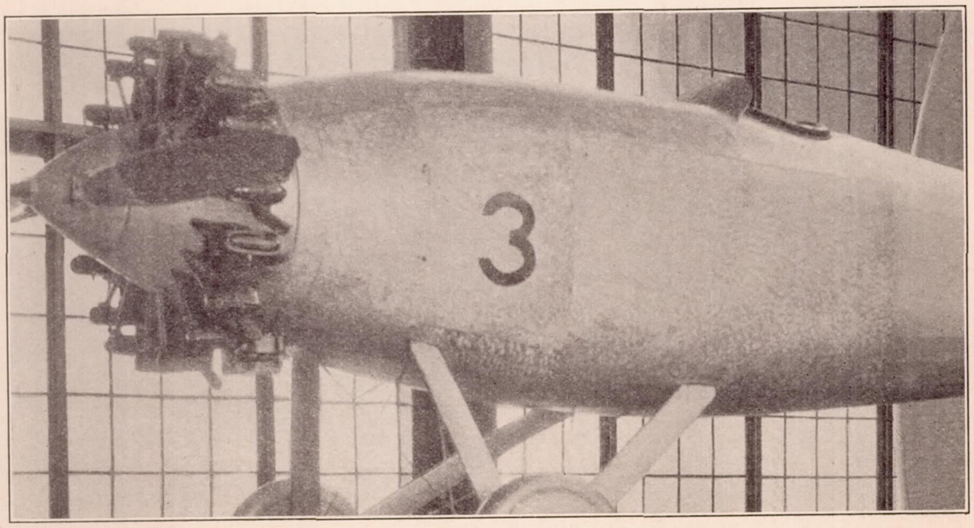

FIG. 11.—Cowling No. 3

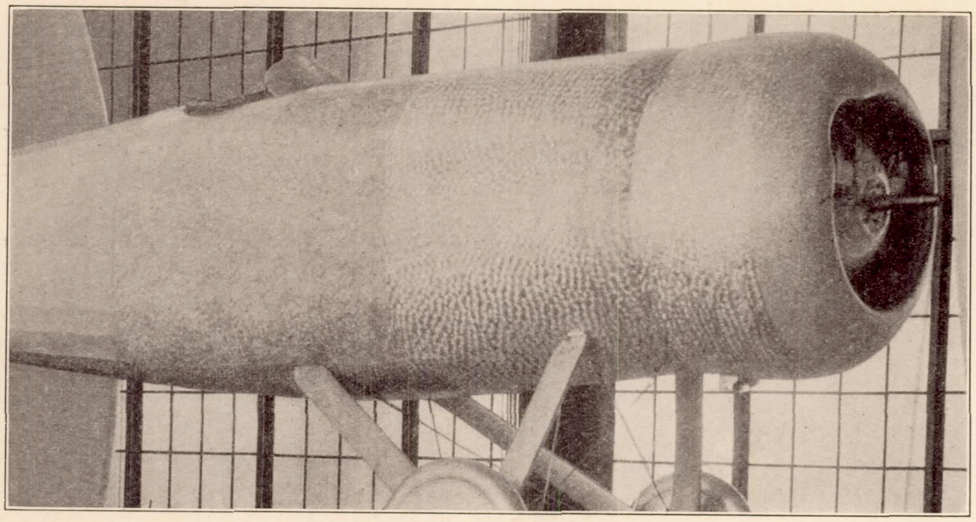

FIG. 12.—Cowling No. 11

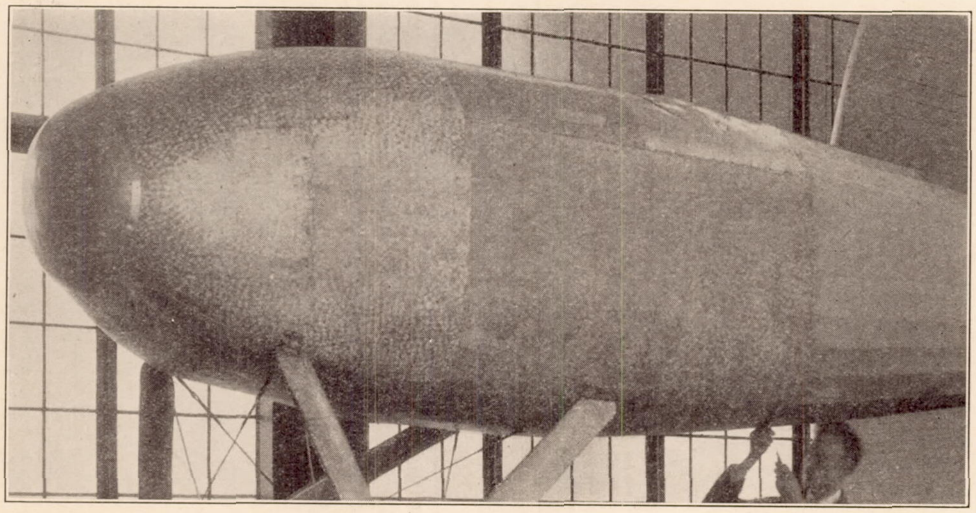

FIG. 13.—No. 1, engine removed

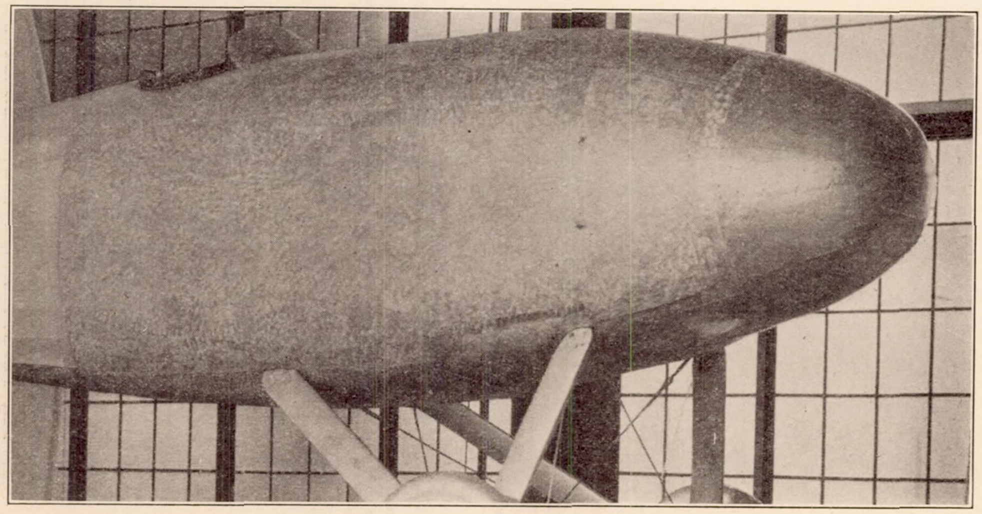

FIG. 14.—No. 2, engine removed

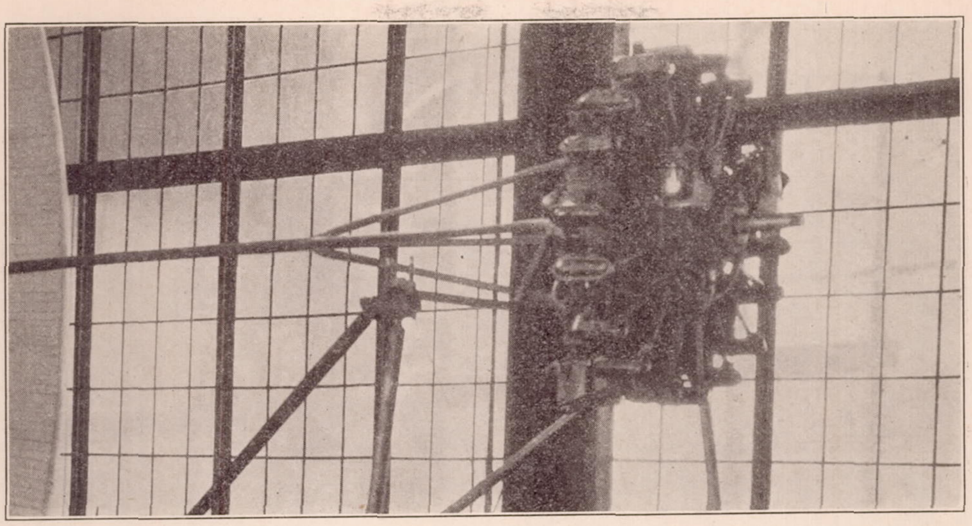

FIG. 15.—No. 12, engine alone

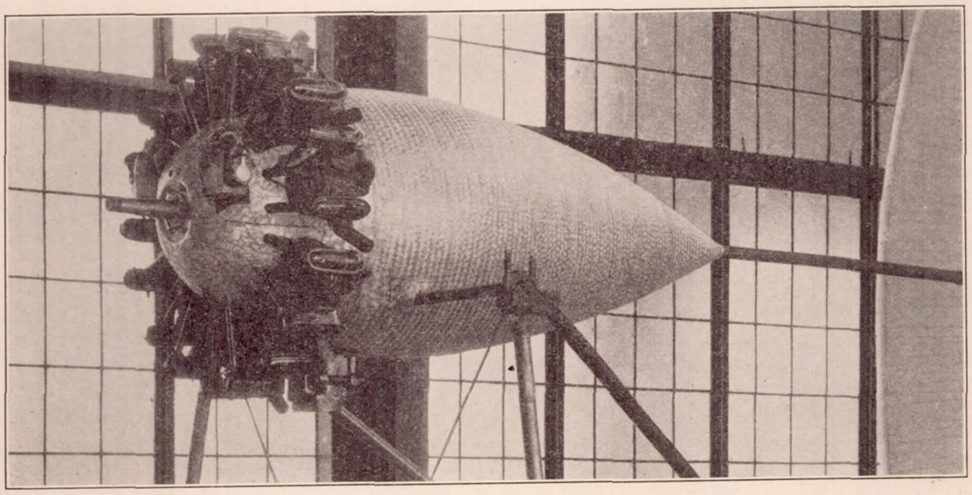

FIG. 16.—No. 13, conventional nacelle

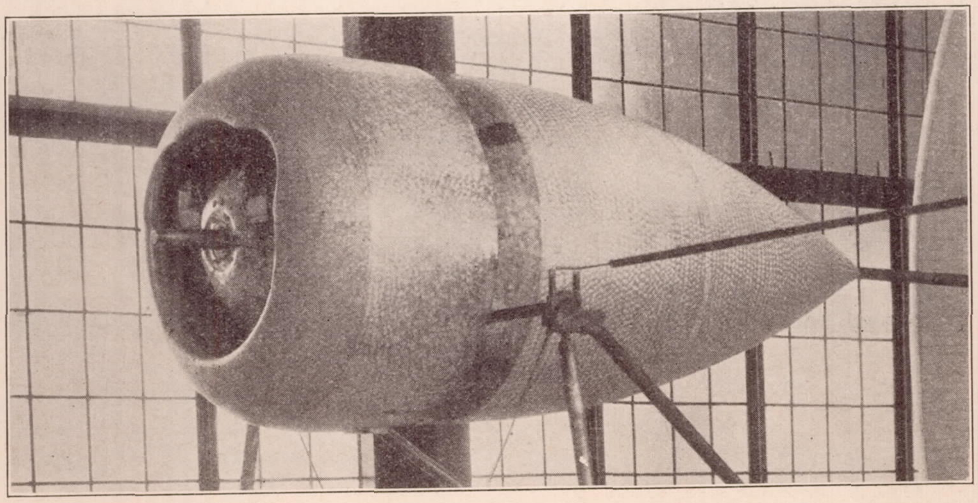

FIG. 17.—No. 14, completely cowled nacelle

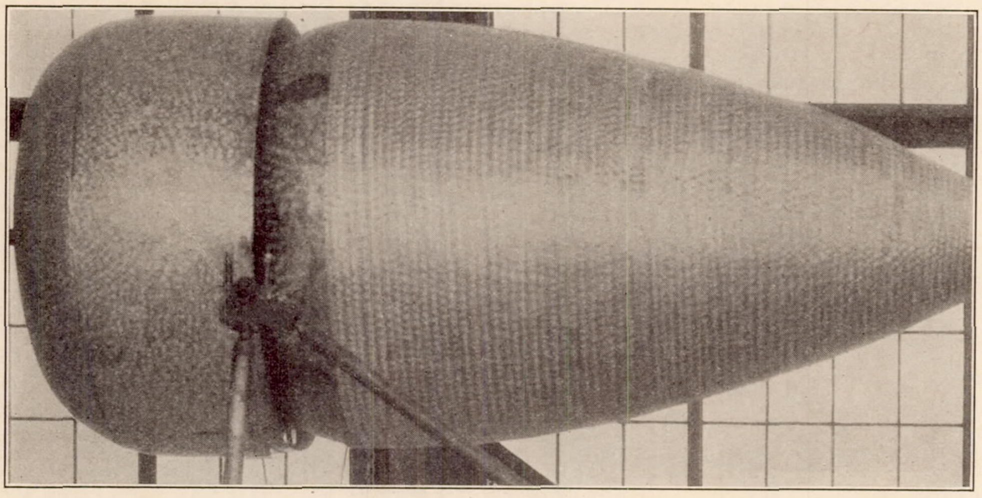

FIG. 18.—No. 14

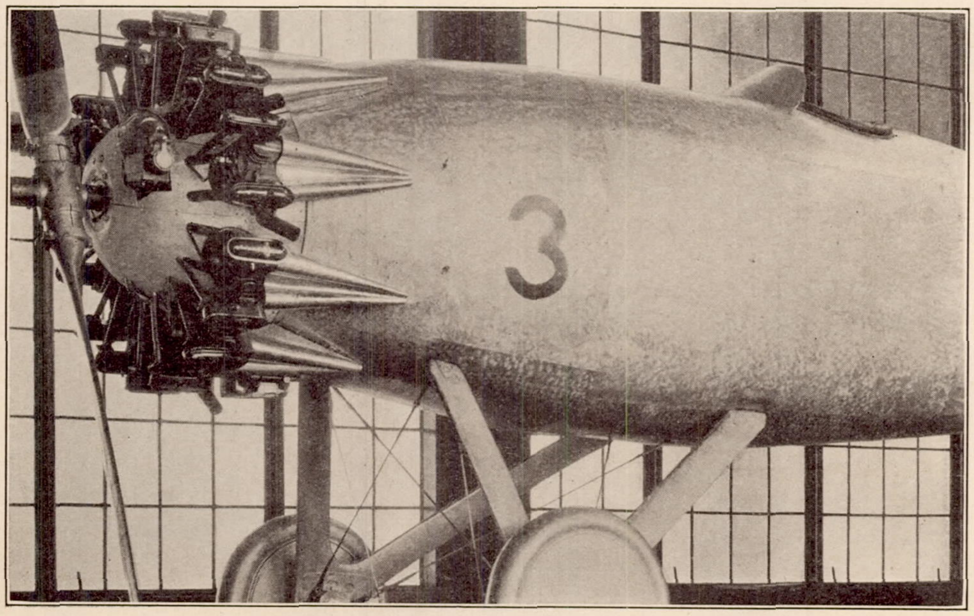

FIG. 19.—Cowling No. 2a, fairings behind cylinders

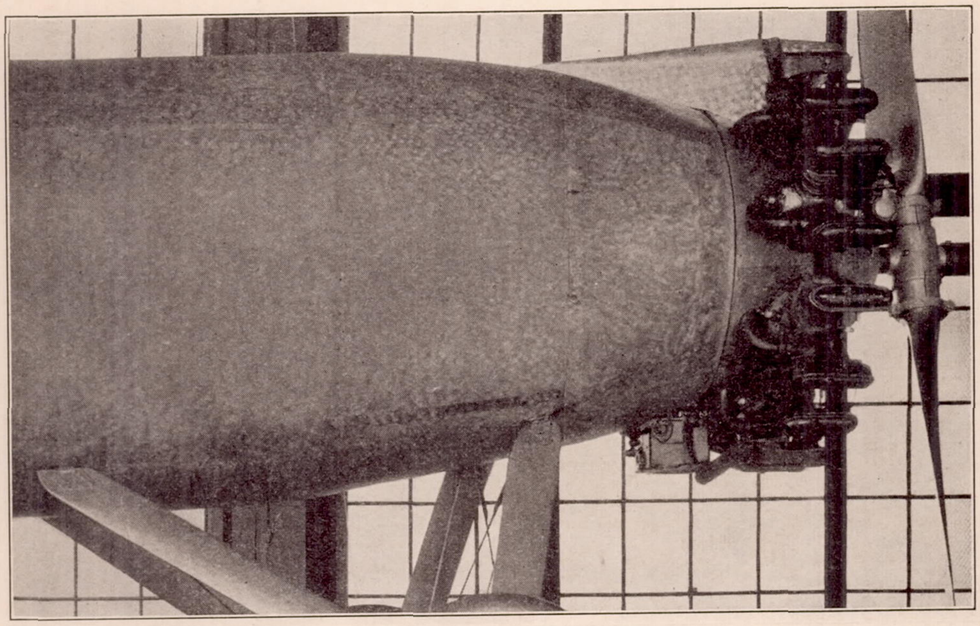

FIG. 20.—Hood over top cylinder for cooling test

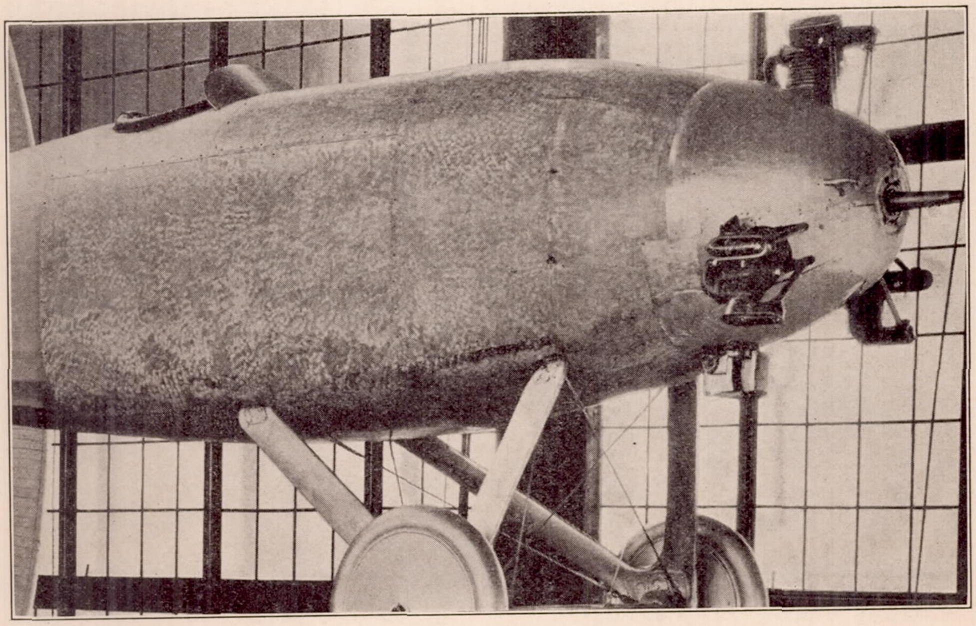

FIG. 21.—Cowling No. 2b, six cylinders removed

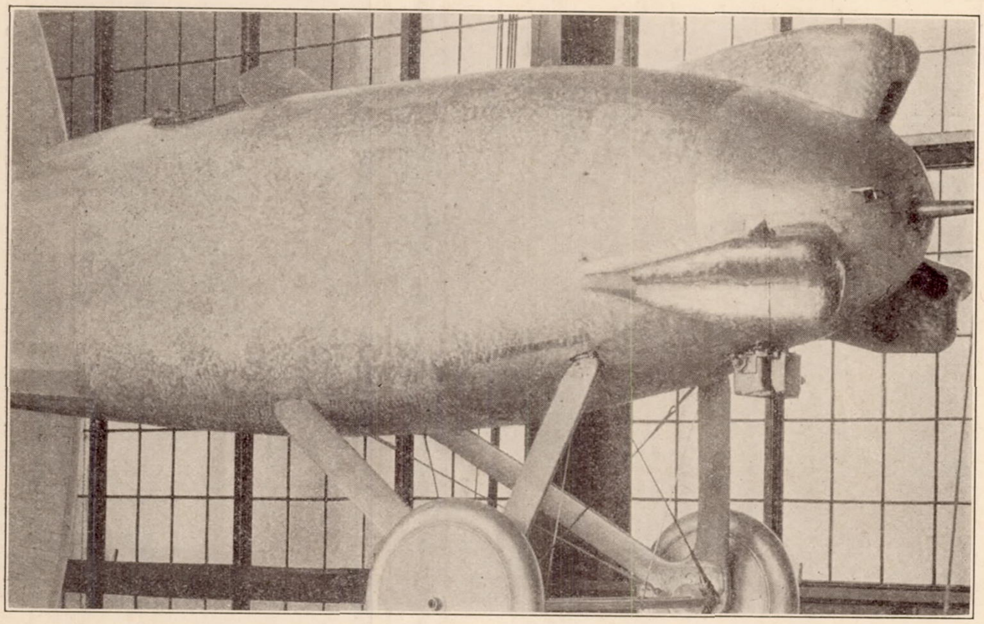

FIG. 22.—Cowling No. 2c, individual hoods with smallest holes

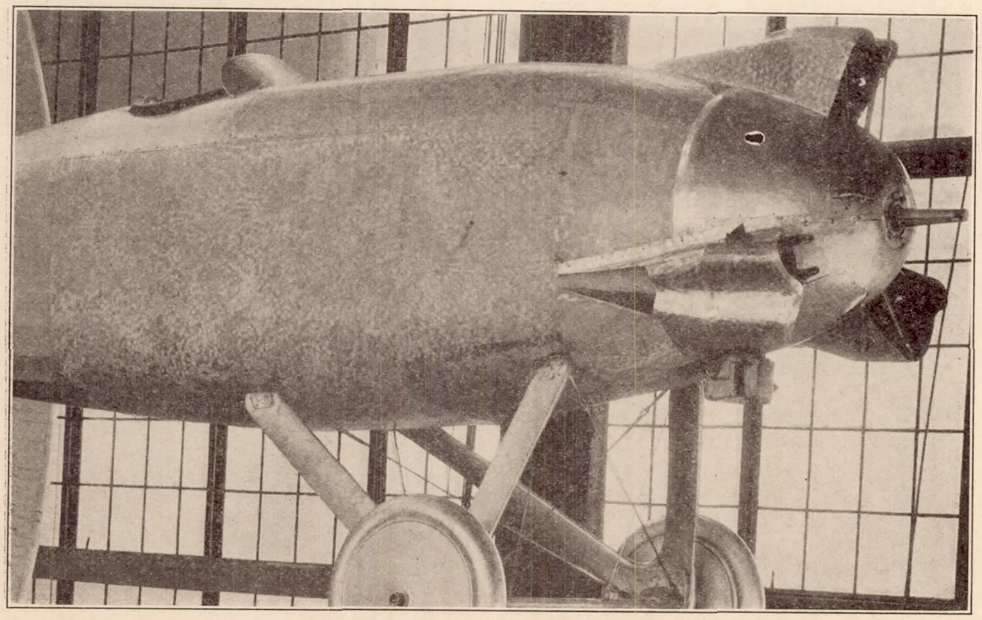

FIG. 23.—No. 2c with front section of hoods removed

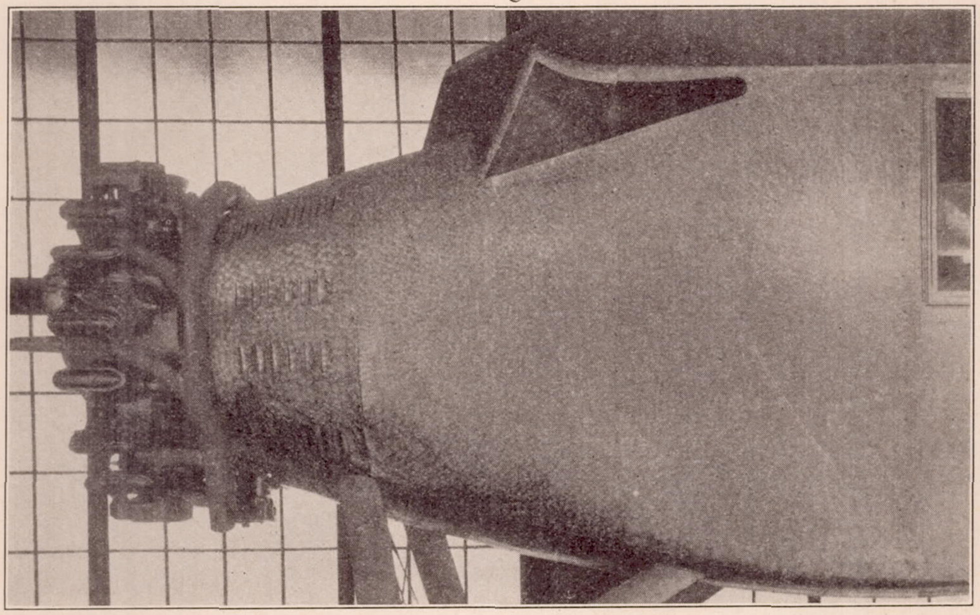

FIG. 24.—Cowling No. 5 with round section exhaust collector ring

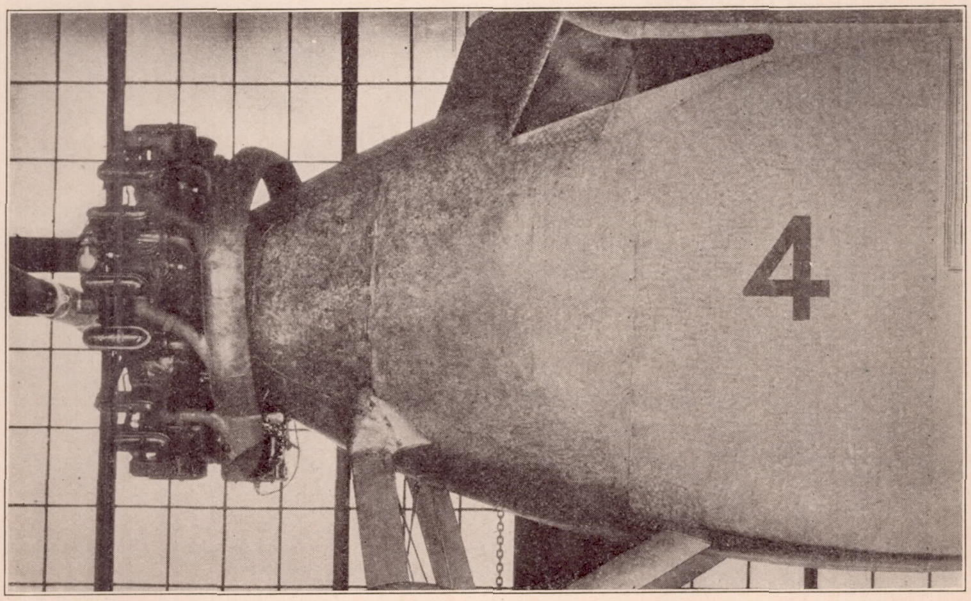

FIG. 25.—Cowling No. 4 with streamline exhaust ring

in and the bottom was rounded throughout the entire length. Also, the front cockpit was eliminated, giving the fuselage unbroken lines from the engine to the tail, except for the rear cockpit. The forward portion of the fuselage was rebuilt to fair with the various cowlings. A UO–1 type landing gear was used to support the fuselage for the tests, but the landing gear drag is not included in the results.

In the tests with the cabin fuselage the cylinder temperatures were thoroughly investigated by means of 69 thermocouples, 47 of which were on the top of No. 1 cylinder. Since with the open cockpit fuselage each form of cowling was the same back to the engine mount as the corresponding cowling with the cabin fuselage, it was not considered necessary to repeat all of the cooling tests. The 47 thermocouples on No. 1 cylinder were retained, however, for checking the previous tests and for further cooling tests with fairings behind and over the individual cylinders.

The general procedure of testing was the same for the open cockpit as for the cabin fuselage, except for the case of the individual hoods or helmets over each cylinder. It was not practical

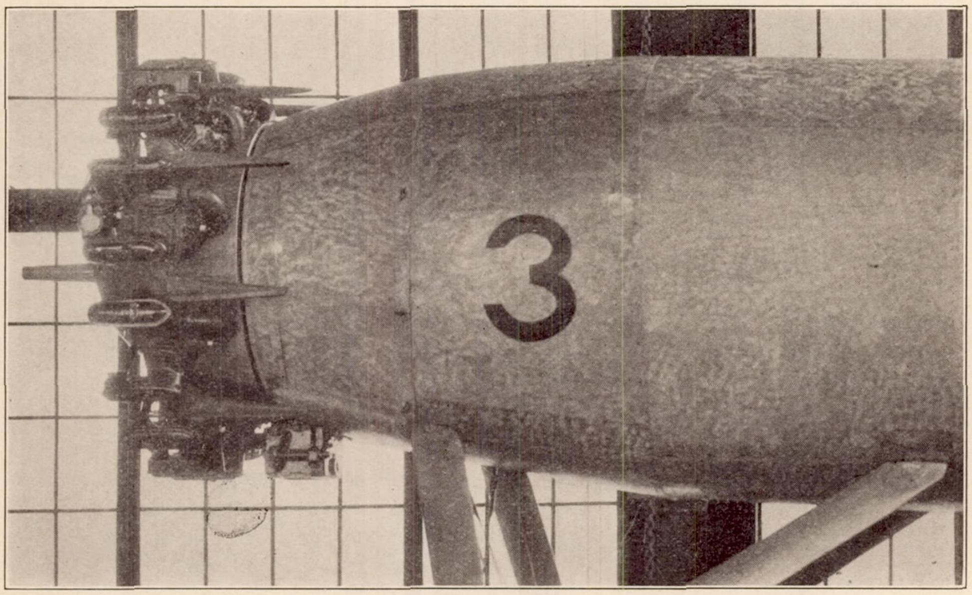

FIG. 26.—Cowling No. 2 with individual tapered exhaust stacks

to put individual hoods over each cylinder of the 9-cylinder "Whirlwind" engine, for with the particular design of this engine there is insufficient room between the cylinders. The drag tests with hoods were therefore made with what was in effect a 3-cylinder "Whirlwind" engine, six of the cylinders having been removed and the cowling faired over as shown in Figure 21. With only the three cylinders, it is thought that the aerodynamic interference between them was negligible. It was not possible, of course, to run the engine with six cylinders removed, so the cooling tests were made with the complete engine, but with only one hood, which was placed over the cylinder fitted with thermocouples. (Cylinder No. 1.)

The cowlings tested in the portion of the investigation covered in this report may be outlined as follows:

OPEN COCKPIT FUSELAGE

No. 1. No cowling over cylinders or crank case. (Figs. 1 and 9.)

No. 2. Cowling over slightly less than one-half of each cylinder and over crank case. (Figs. 2 and 10.)

No. 3. Same as No. 2 but with spinner. (Figs. 3 and 11.)

No. 11. Single cowling completely covering entire engine with internal cowling similar to No. 2 over lower portion of cylinders and crank case. (Figs. 4 and 12.)

NACELLES

No. 12. Engine alone. No cowling. (Fig. 15.)

No. 13. Conventional cowling, nose same as Nos. 2 and 5. (Figs. 5 and 16.)

No. 14. Complete cowling, nose same as No. 11. (Figs. 6 and 17.)

INDIVIDUAL CYLINDER FAIRINGS

No. 2a. Same as No. 2 but with individual fairings behind each cylinder. (Figs. 7 and 19.)

No. 2b. Same as No. 2 but with only three cylinders. (Figs. 2 and 21.)

No. 2c. Same as No. 2b but with hoods completely covering the cylinders. (Figs. 8, 22, and 23.)

In the cooling tests the engine was run with wide open throttle at an air speed of 80 M. P. H. until the temperatures became substantially constant, which usually required about 10 minutes. If the cooling with any cowling was not approximately the same as for the uncowled engine, an attempt was made to modify the cowling until it was so.

Drag tests were run with all of the original and modified cowlings; with the open cockpit fuselage with the engine removed and the nose rounded; and with the windshield removed and the cockpit covered. Special tests were also made on the engine drag with various exhaust stacks and on the completely cowled nacelle with the slot covered.

The propulsive efficiency was found with an adjustable pitch metal propeller (fig. 31 of Reference 1) at two pitch settings, with cowling Nos. 1, 2, 3, and 11. This propulsive efficiency includes the increase in drag of all parts of the body affected by the slip stream and also the effect of the body interference on the propeller characteristics.

COOLING TESTS

It was not thought necessary to run cooling tests with cowling Nos. 1, 2, 3, and 11 on the open cockpit fuselage, because the same forms had all been tested on the cabin fuselage and No. 11 had proven satisfactory in flight tests also. (Appendix of Reference 1.) However, check tests were made on the temperatures of cylinder No. 1 with cowling Nos. 2 and 3. The temperatures, which are recorded in Table I, were somewhat higher than in the cabin fuselage tests, probably because the cylinder was developing greater power.

Since the engine cowlings on the nacelles were also the same as the corresponding forms on both fuselages, no cooling tests were necessary and the engine was not run, the drag tests only being made. This simplified the nacelle installations greatly.

With the No. 2 cowling equipped with an individual fairing behind each cylinder (figs. 7 and 19), the cooling, as shown in Table I, was about the same as with the regular No. 2 cowling without the fairings.

With the individual hood, as originally constructed, on cylinder No. 1 (figs. 8 and 22), the temperatures became excessive in less than three minutes of full throttle running at an air speed of 80 M. P. H. The entire front section was then removed (fig. 23) and an equivalent area cut in the rear, after which the temperatures still became somewhat higher than without the hoods, but were not considered excessive. It is no doubt possible that an improved hood could be designed with which the cooling would be considerably better, but the results of the drag tests did not indicate that the effort would be worth while.

RESULTS OF DRAG TESTS

The observed drag test data are given in Table II and the results are plotted in Figures 27, 28, and 29.

Open cockpit fuselage.

The drag of the open cockpit fuselage (without supports or landing gear) with the various cowlings is given for an air speed of 100 M. P. H. in the following table:

Cowling	Fuselage and engine drag, pounds at 100 M. P. H.	Reduction from uncowled engine, pounds at 100 M. P. H.
No. 1. Engine uncowled	141	0
No. 2. No spinner	136	5
No. 3. Spinner	132	9
No. 11. Complete cowling	73	68
No. 1. Engine removed and nose rounded	42	99
No. 2. Engine removed and cylinder holes closed	42	99
No. 1. Engine and windshield removed and cockpit covered	28	113

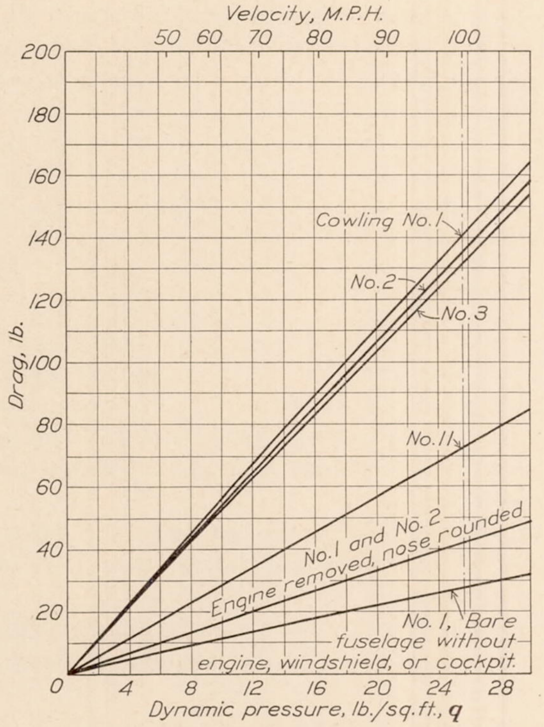

FIG. 27.—Drag of open cockpit fuselage and engine with various cowlings

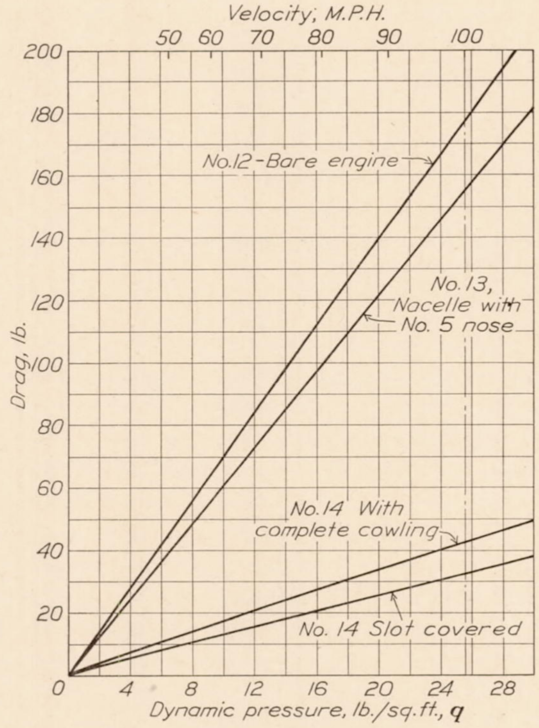

FIG. 28.—Drag of J-5 engine with various nacelles

The last three items have been included in order to show the additional drag due to the engine on this fuselage, and the last item, in which the windshield and cockpit are eliminated as well as the engine, also affords a direct comparison with the nacelles. It is interesting that both No. 1 and No. 2, which had decidedly different nose shapes, had the same drag when the engine was removed. Using either of these as a basis, therefore, the uncowled engine is responsible for an increase in drag of 99 pounds at 100 M. P. H. on the open cockpit fuselage.

As in the case of the cabin fuselage, the outstanding feature of these drag tests is the low drag of the complete cowling, No. 11. The conventional forms of cowling, Nos. 2 and 3, have but a very slight effect on the drag.

The windshield and cockpit are responsible for a drag of 14 pounds at 100 M. P. H., which is 50 per cent of the drag of the bare closed fuselage.

The drag of the fuselage with uncowled engine but without cockpit is about 127 pounds at 100 M. P. H., which is over four and one-half times that of the bare closed fuselage without the engine.

Nacelles.

The drags of the three nacelles at 100 M. P. H. are as follows:

Nacelle	Drag in pounds at 100 M. P. H.	Reduction from uncowled engine, pounds at 100 M. P. H.
No. 12. Engine alone, uncowled	178	0
No. 13. Conventional cowling	155	23
No. 14. Complete cowling	43	135

The nacelles represent the extremes of the features found in the open and cabin fuselage tests. The drag of the bare engine by itself is just over half that of a flat disk having the same outside diameter—45 inches. The conventional nacelle has 23 pounds less drag at 100 M. P. H. than the engine alone, but with the nacelle having the new complete cowling the reduction is 135 pounds. Thus, the drag with the completely cowled nacelle is 112 pounds less at 100 M. P. H. than that with the conventional nacelle.

Individual fairings behind cylinders.

The drag of No. 2a (No. 2 cowling with an individual fairing behind each cylinder, figs. 7 and 19) was found to be 134 pounds at 100 M. P. H., or just 2 pounds less than that of the standard No. 2 cowling without the fairings. It may, therefore, be said that fairings of this type behind cylinders similar in shape to those of the "Whirlwind" J-5 engine, decrease the drag to a practically negligible extent.

Hoods inclosing each cylinder.

As stated previously, due to the small space between the cylinders of the J-5 engine, for the tests with individual hoods six cylinders were removed, leaving in effect a 3-cylinder engine as shown in Figure 21. In the cooling tests the cylinder temperatures became excessive at 80 M. P. H. with the original hood, which had openings in the front and rear of the same area per cylinder as the successful complete cowling, No. 11. It was thought, however, that this type of cowling might have some use on airplanes having a high enough speed to give proper cooling. The drag was, therefore, measured for the hooded 3-cylinder engine with four different sized openings in the front and rear of the hoods, including the original one of 4 by 6 inches, one 5 by 7 inches, one 6 by 8 inches, and one with the entire front section removed. (Figs. 8, 22, and 23.)

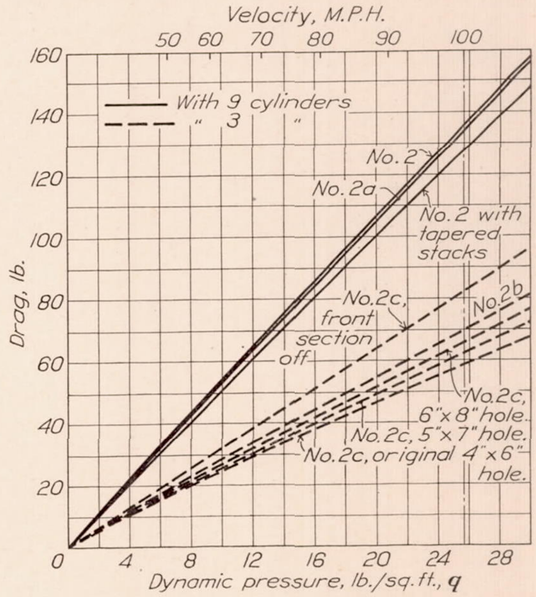

FIG. 29.—Drag of cowling No. 2 with individual fairings and hoods

In each case the outlet area was made equal to the inlet area. The values of the drag are as follows:

Cowling	Drag in pounds at 100 M. P. H.	Reduction from 3 cylinders on No. 2 nose, pounds at 100 M. P. H.
No. 2b. No. 2 nose with 3 cylinders projecting	70	0
No. 2c. Hoods with 4 by 6 inch openings	59	11
No. 2c. Hoods with 5 by 6 inch openings	62	8
No. 2c. Hoods with 6-by 8 inch openings	66	4
No. 2c. Hoods with front section removed	82	−12
No. 2. Engine removed and cylinder holes covered	42	28

The three cylinders add 28 pounds, or 9.3 pounds per cylinder, to the drag of the bare No. 2 fuselage, as compared with 94 pounds, or 10.4 pounds per cylinder, for the nine cylinders. Thus, the additional interference with the 9-cylinder engine makes the drag per cylinder 12 per cent higher.

With the hoods having the smallest openings and the lowest drag, the drag is 11 pounds less than with the three exposed cylinders. This represents a saving of only 3.7 pounds per cylinder, whereas the saving over No. 2 with the complete No. 11 cowling is 7 pounds per cylinder. With the larger holes the reduction in drag is even less, and in fact with the largest opening the drag was increased 12 pounds over that for the exposed cylinders. While it is possible that hoods with considerably improved drag and cooling properties could be developed, the results with those tested indicate that, for cylinders having a shape similar to those of the J-5 engine, the effort would not be warranted.

Effect of various exhaust stacks on drag.

In order to make the investigation of the drag of the "Whirlwind" engine complete, the engine was tested with four different types of exhaust stacks as follows (see also Reference 3):

(1) Original individual stacks, 1¾ inches in diameter and approximately 5 inches long, projecting outward and somewhat to the rear, as shown in Figure 9. (These stacks were used throughout the cowling tests.)

(2) Round collector ring 36 inches in mean diameter, having a circular cross section 3 inches in diameter, the exhaust from all nine cylinders coming out on the left side. (Fig. 24.)

(3) Stream-line collector ring similar to the above except that it had a stream-line cross section 2 inches wide and 5 inches long with the same cross-sectional area as that of a 3-inch circle. (Fig. 25.)

(4) Individual tapered stacks which projected rearward and allowed the exhaust to escape through a longitudinal slot. (Fig. 26.)

The original short stacks had the greatest drag. The reduction in drag from that with the original stacks is given for the various stacks in the following table:

Type of exhaust stack	Reduction in drag from that with original short stacks, pounds at 100 M. P. H.	
	No cowling over engine Nos. 1 or 4	Conventional cowling Nos. 2 or 5
Original, short individual stacks	0	0
Round section collector ring	2	0
Stream-line section collector ring	2	2
Individual tapered slotted stacks	----------	8

It is notable that there is very little difference in drag with the first three types of stacks, but that an appreciable reduction is obtained with the individual tapered stacks.

RESULTS OF PROPELLER TESTS

Propeller tests were made with cowling Nos. 1, 2, 3, and 11 on the open cockpit fuselage. The engine could not, of course, be run with the cowling having individual hoods, for which six cylinders had been removed, and the power could not have been measured with the nacelles without reconstructing the test fuselage with its special dynamometer. Moreover, it was thought that the effect of the nacelles on the propulsive efficiency would be similar to that of the open cockpit fuselage with the corresponding cowling.

The propulsive efficiencies obtained are shown in Figure 30 for a propeller blade angle setting of 15° at the 42-inch radius, and in Figure 31, for a setting of 23° at the 42-inch radius.

(These angle settings correspond to pitch-diameter ratios of 0.66 and 1.02, the pitch being taken at 75 per cent of the radius. The pitch of this propeller is approximately uniform for all working sections when the pitch-diameter ratio is about 0.5.)

The curves of propulsive efficiency with the conventional cowlings are all very nearly the same, and they are also about the same as the corresponding curves with the cabin fuselage. The propulsive efficiency with the new complete cowling on the open cockpit fuselage, however, is about 2.5 per cent greater than with any of the others.

DISCUSSION

The drag tests afford several interesting comparisons, a few of which will be discussed here.

The drag of the engine alone is 178 pounds at 100 M. P. H., but it caused an increase of only 99 pounds when entirely exposed on the nose of the open cockpit fuselage, and only 85 pounds on the cabin fuselage. Thus, it is evident that the larger the body behind the engine the less is the drag due to the engine. In this connection it should be mentioned that the open cockpit fuselage used in these tests was larger in cross section than the fuselages of most single-

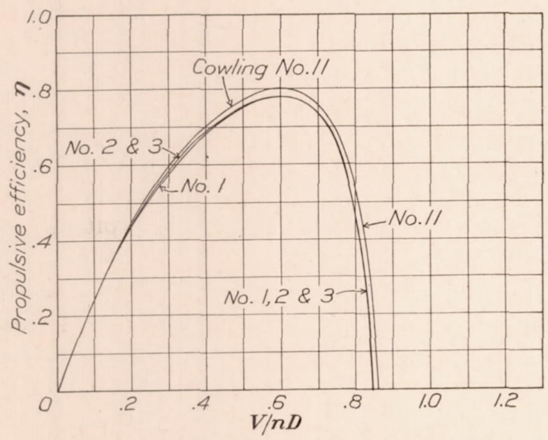

FIG. 30.—Propeller No. 4412 (15° at 42″) on various cowlings with open cockpit fuselage and J-5 engine

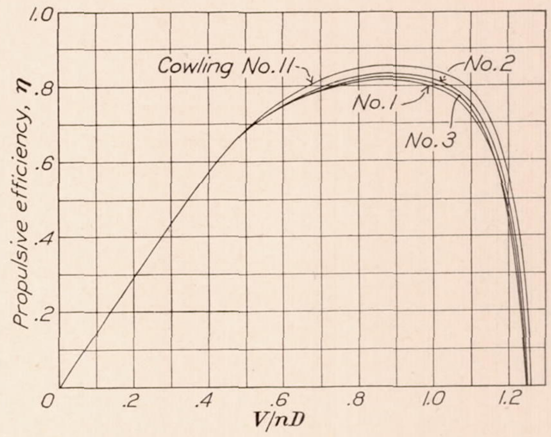

FIG. 31.—Propeller No. 4412 (23° at 42″) on various cowlings with open cockpit fuselage and J-5 engine

place airplanes, and that the drag due to the engine with most airplanes of that type will ordinarily be greater. This effect is so pronounced that even though the drag of the larger body is proportionately greater, the total drag of the body and engine is larger with the smaller body, as shown by the following table:

Body and cowling number	Fuselage and engine drag, pounds at 100 M. P. H.
Cabin fuselage, No. 5	119
Open cockpit fuselage, No. 2, cockpit covered	122
Nacelle, No. 13	155

The drag of the open fuselage without cockpit was obtained by subtracting from the actual drag the 14 pounds found for the windshield and cockpit when the engine was removed and the nose rounded. The windshield would probably have less drag in the turbulent air behind the engine, so that the drag given in the above table for the open fuselage is probably a little low. It should be noted that all of these drag values are for a moderate degree of conventional cowling.

The drags of the three closed bodies with the N. A. C. A. complete cowling are as follows:

Body and cowling number	Drag, pounds at 100 M. P. H.	Reduction from uncowled engine, pounds at 100 M. P. H.	Percentage reduction of drag of uncowled engine
			Per cent
Cabin fuselage, No. 10	75	50	59
Open cockpit fuselage, No. 11, cockpit covered	59	68	69
Nacelle, No. 14	43	135	76

It is seen from this table that the smaller the body behind the engine the larger is the reduction in drag with the complete cowling. In fact, even the percentage reduction of the drag due to the uncowled engine is greater with the smaller bodies.

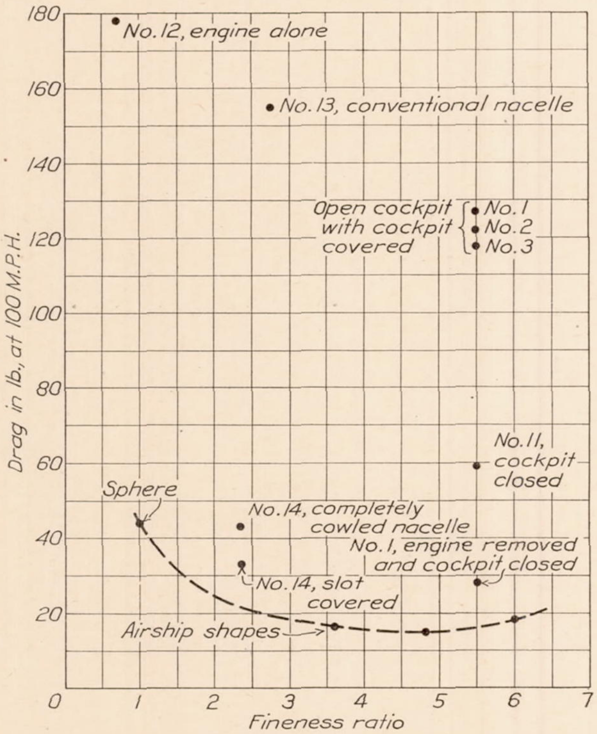

FIG. 32.—The expression "open cockpit with cockpit covered" means that the drag of the cockpit and windshield has been deducted so that the tests are comparable with the nacelle tests

The drag of the open cockpit fuselage with the complete cowling and the cockpit covered, it will be noticed, is 59 pounds, as compared with only 43 pounds for the nacelle with the complete cowling. Since both have the same identical forward portion and the same maximum cross section, the difference seems rather large. It may be partially explained by the fact that the rear half of the open cockpit fuselage was covered with fabric and was not very smooth.

The drags of several streamline airship bodies of various fineness ratios are plotted in Figure 32, the data being obtained from high Reynolds number tests in the variable density wind tunnel. The drag values are all for bodies of the same maximum diameter as the completely cowled nacelle and open fuselage (46 inches), and for an air speed of 100 M. P. H. The drag at any fineness ratio may be considered an ideal with which to compare the drag of a fuselage or nacelle of the same fineness ratio, and with this in view, the drags for the various nacelles and open fuselages with cockpit covered have also been plotted on Figure 32.

The drag of the completely cowled nacelle is only about 22 pounds greater than that of a good airship shape having the same maximum diameter and fineness ratio. The further possible improvement is therefore slight compared with the 112 pounds improvement over a good conventional nacelle, especially considering the fact that the engine must be cooled. The 22 pounds may be looked upon as the cost of cooling the engine with the present completely cowled nacelle. Based on the difference in drag between the completely cowled fuselages and the fuselages without the engine, the cost in drag to cool the engine with the open cockpit fuselage is 31 pounds, and that with the cabin fuselage is 35 pounds all at an air speed of 100 M. P. H.

Effect of slot.

When the slot was originally designed for the complete cowling it was hoped that it would tend to reduce the drag because of its effect on the boundary layer. A test made on the nacelle with the slot covered, however, showed that the drag is 10 pounds less at 100 M. P. H. without the slot. The nacelle with the slot covered had only about 60 per cent more drag than the airship body, which seems remarkably low considering the blunt nose with the open pocket in the center.

During one of the drag runs with the completely cowled nacelle with the slot open, a rough survey was made of the air flow coming out of the slot and also of that just outside the slot. It was found that the velocity of the air coming out was fairly constant across the slot and had a value of 9 per cent lower than the velocity of the tunnel air stream. Outside the body but close to it, the velocity of the air was also constant for a distance of several inches and had a value of 11 per cent greater than the tunnel velocity. The velocity of the air immediately outside of the slot was, therefore, 22 per cent higher than that coming out of the slot, and the change from the low to the high velocity took place within one-half an inch or less. The boundary layer of the outside air at the slot is apparently small on a body of this form, and no great reduction in drag could be expected from the slot, even if it were of the best possible proportions. It is likely that the cooling air could be collected after it had passed the cylinders, and directed out to the outside flow through one or two openings, say at the bottom or both sides, with no increase in drag over that with the annular slot. The annular slot is, however, a very convenient means for getting the used cooling air back to the general outside flow.

Check between wind tunnel and flight tests.

The appendix to the report on the first part of this investigation (Reference 1) describes flight tests on a Curtiss AT–5A airplane with the N. A. C. A. complete cowling. The original cowling was similar to No. 1, with the engine entirely exposed, but the fuselage was smaller in cross section than that of No. 1. The airplane had a 200 HP. Wright "Whirlwind" J–5 engine similar to the one used for the cowling tests in the 20-foot wind tunnel.

The maximum sea-level speed of this airplane was increased from 118 M. P. H. with the original cowling to 137 M. P. H. with the complete cowling, an increase of 19 M. P. H.

It is interesting to compute from the flight tests the difference in drag required to cause this increase in speed, and to compare this with the results of the wind-tunnel tests. Part of the increase in speed is due to the lower induced drag at the higher speed, and part is due to higher propulsive efficiency. According to full scale wind-tunnel tests on the identical propeller used in the flight tests, the propulsive efficiency would be 2.8 per cent greater at 137 M. P. H. than at 118 due to the higher pitch, and as shown by the tests in this report, a further increase of 2.5 per cent would be obtained due to the complete cowling. The propulsive efficiencies (including body interference and slip-stream effect) are given below along with calculations of the drag with each cowling:

	AT–5A with original cowling	AT–5A with complete cowling
Maximum speed, M. P. H.	118	137
Horsepower (approximate)	200	200
Propulsive efficiency	0.760	0.801
Thrust horsepower	152	160.2
Drag $=\dfrac{\text{T. HP.}\times 550}{\text{Velocity in feet per second}}$	[1] 484	[1] 439
Drag at same angle of attack at 100 M. P. H.	[1] 348	[1] 234
$C_L=\dfrac{L}{qS}=\dfrac{2471}{q\times 250}$	0.2780	0.2058
$C_{Di}=\dfrac{C_L^2 S}{\pi b^2}=\dfrac{C_L^2\times 250}{\pi\times 33.4^2}$	0.00551	0.00302

[1] Pounds.

The difference in induced drag due to the two different angles of attack, when reduced to a speed of 100 M. P. H., becomes

$$\Delta C_D qS=(0.00551-0.00302)\times 25.57\times 250=16 \text{ pounds.}$$

There are other differences in drag due to the fact that the complete cowling covered certain fittings and a portion of the landing gear struts, which were exposed with the original cowling, but in a comparison of the AT–5A results with the wind-tunnel results these differences approximately balance the difference between the tapered exhaust stacks used on the AT–5A and the cylindrical stacks used in the wind-tunnel tests.

The reduction in drag at 100 M. P. H. due to the complete cowling is then

$$(348-234)-16=98 \text{ pounds.}$$

In Figure 33 the corresponding reduction in drag at 100 M. P. H. is plotted for three of the wind-tunnel tests, on the basis of the cross-sectional area of the bodies behind the exposed engine.

The point calculated from the flight tests, it will be noticed, falls on the curve through the wind-tunnel points. The fact that the flight-test point falls exactly on the curve is merely fortuitous, for the calculated drag reduction can not be expected to be more than approximately correct. Within the limitations of the calculations, however, the agreement between the flight and wind tunnel tests is excellent, and the increase in maximum speed of 19 M. P. H. is substantiated by the results of the wind-tunnel tests.

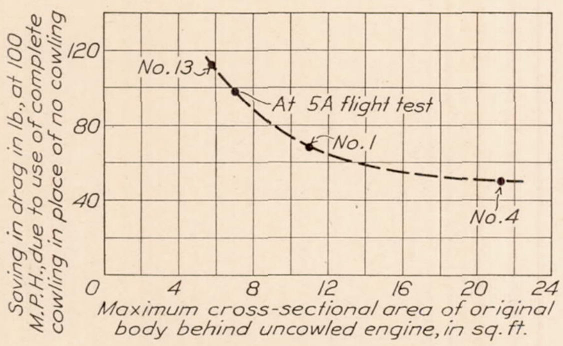

FIG. 33.—Comparison of flight and wind tunnel tests

CONCLUSIONS

1. The results and conclusions given in the report covering the first part of this investigation including the tests with a cabin fuselage (Reference 1) are substantiated.

2. Individual fairings behind cylinders having a form similar to those of the J–5 engine have no appreciable effect on the drag.

3. Individual hoods over each cylinder result in but a slight reduction in drag when used on cylinders similar in shape to those of the J–5 engine.

4. The only large reductions in drag were obtained with the new complete cowling on Nos. 11 and 14. The reduction in drag with the complete cowling on the nacelle was remarkable, being more than twice as great as that found with the cabin fuselage, and being 76 per cent of the drag of the totally exposed engine alone.

5. The reduction in drag obtained with the complete cowling is greater for the smaller original bodies behind the exposed or partially exposed engine.

6. The reduction of drag as computed from flight tests with the complete cowling on an AT–5A airplane is in excellent agreement with that found by the wind-tunnel tests.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
December 17, 1928.

REFERENCES

1. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Engine in a Cabin Fuselage. N. A. C. A. Technical Note No. 301 (1928), later published as "Drag and Cooling with Various Forms of Cowling for a 'Whirlwind' Radial Air-cooled Engine–I." N. A. C. A. Technical Report No. 313. (1929.)
2. Weick, Fred E. and Wood, Donald H.: The Twenty-foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300. (1928.)
3. Weick, Fred E.: The Drag of a J–5 Radial Air-cooled Engine. N. A. C. A. Technical Note No. 292. (1928.)

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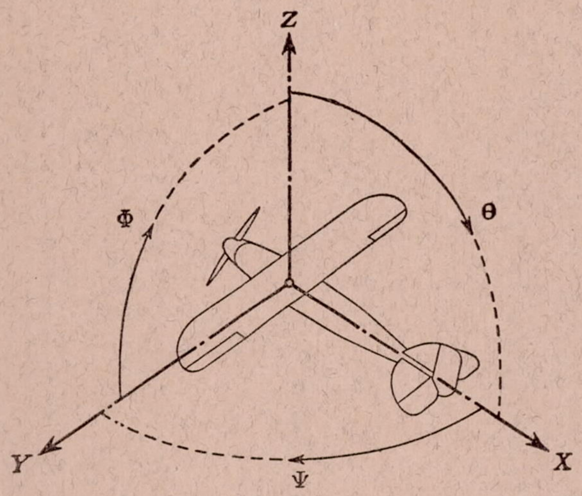

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\ V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.